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Stephanie A. Shwiff
USDA/APHIS/WS National Wildlife Research Center, stephanie.a.shwiff@aphis.usda.gov

Ray T. Sterner
USDA, Wildlife Services, National Wildlife Research Center

John W. Turman
USDA/APHIS/WS National Wildlife Research Center

Brian D. Foster
USDA, Wildlife Services, National Wildlife Research Center

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ANALYSIS

Ex post economic analysis of reproduction-monitoring and predator-removal variables associated with protection of the endangered California least tern

Stephanie A. Shwiff[a,*], Ray T. Sterner[a], John W. Turman[b], Brian D. Foster[c]

[a]*USDA, Wildlife Services, National Wildlife Research Center, 4101 LaPorte Ave, Fort Collins, CO 80521-2154, United States*
[b]*USDA, Wildlife Services, 9380 Bond Avenue, El Cajon, CA 92021, United States*
[c]*The Zoological Society of San Diego, P.O. Box 120551, San Diego CA 92112-0551, United States*

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Abstract

Important nest sites for the endangered California least tern remain at the U.S. Marine Corps Base, Camp Pendleton, CA; these terns comprise approximately 17% of the state's breeding population. This paper presents an empirical analysis of annual, fixed-cost budgets expended for reproduction-monitoring and predator-removal activities to protect this shorebird. The ex post study covered the inclusive 7-year period between 1995 and 2001. Separate regression analyses were computed using 15 biological (X_B), economic (X_E), and meteorological (X_M) variables. In separate analyses, 14 of these variables served as independent variables to predict each of four dependent tern observation variables (i.e., Y_{nests}, Y_{eggs}, $Y_{fledglings}$, and Y_{adults}), with certain variables "lagged" (i.e., regressed after fixed intervals) to compensate for delayed effects of predator management. Mean net current annual reproduction-monitoring and predator-removal budgets were US$80,115 and US$78,178, respectively; annual fiscal data were converted to "proxy" variables of personnel time (h) for analysis of economic effects. Mean time spent in reproduction-monitoring (3.12 h/day) and predator-removal activities (6.96 h/day) differed greatly. Expenditures for both reproduction-monitoring and predator-removal staff hours were associated with greater counts of tern eggs and adults, with increased monitoring hours predictive of finding more tern nests and fledglings and increased predator-removal hours linked with fewer fledgling counts. No meteorological variables predicted any dependent variable. Economic issues involved in recovery of threatened and endangered species (TS/ES) are discussed.
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Keywords: Endangered species; California least tern; Predator management; Reproduction monitoring; Regression analysis; Economics

1. Introduction

In the United States, the Endangered Species Act, perhaps more than any other single legislative event,

* Corresponding author. Tel.: +1 970 266 6150; fax: +1 970 266 6157.
E-mail address: stephanie.a.shwiff@aphis.usda.gov (S.A. Shwiff).

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reinforced the idea of qualitative and quantitative valuations for rare animals and plants (see U.S. Department of the Interior, 1973). Still, few studies have attempted to empirically measure the effectiveness of fiscal variables on the production of threatened and endangered species (TS/ES).

The California least tern (*Sterna antillarium brownii*) was one of the originally listed TS (sic ES) in the United States (Federal Register 35:8491–8498, 1970). This small (<25 cm), ground-nesting seabird inhabits the Pacific Coast of Central and North America, migrating north and south annually to nest during the spring and summer months in colonies on coastal dunes and beaches from southern Baja to San Francisco, CA (Bent, 1921; Grinnell and Miller, 1944). A century ago, breeding populations numbered in the thousands (Secrist, 1915), but by the time of its listing, the total known population numbered between 300 and 600 nesting pairs (U.S. Department of the Interior, 1973). Predation, coastal development, and human recreation have impacted recruitment, while dredging, filling, and water pollution continue to degrade offshore fisheries (see Butchko and Small, 1992; Caffrey, 1994).

Important nest sites of the California least tern remain at the U.S. Marine Corps Base, Camp Pendleton. These terns comprise approximately 17% of the total California breeding population (Caffrey, 1994). In recent years, fixed-cost agreements have been effected here to monitor reproduction and to limit predation. Reproduction monitoring has delineated tern reproductive success, has improved surveillance, and has guided predator management activities. Similarly, predator management has been practiced since 1988 (see Avery et al., 1995; Butchko, 1990; Butchko and Small, 1992).

Here, we describe an ex post study of monetary expenditures to protect the California least tern at Camp Pendleton. Seven years (1995–2001) of annual fixed-cost budgets for reproduction-monitoring and predator-management activities were analyzed. Descriptive, correlation, and regression statistics were used to characterize the influence of 14 biological, economic, and meteorological variables (e.g., predators removed, monitoring hour, precipitation) upon four dependent variables of tern reproduction (i.e., nests, eggs, fledglings, and adults).

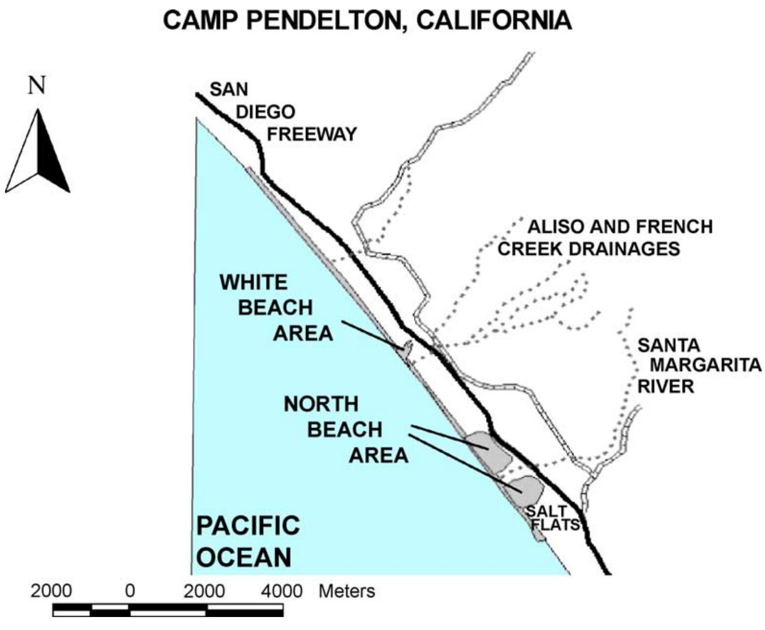

Fig. 1. Map of Camp Pendleton showing main nesting areas of the California least tern.

2. Approach and methods

2.1. Camp Pendleton site

The U.S. Marine Corps Base, Camp Pendleton, CA is a main amphibious training center located in northwest San Diego County. The base encompasses ≈50,000 ha, with ≈27 km of coastline along the Pacific Ocean (Fig. 1). California least terns show annual nesting fidelity to the site, with some data suggesting that over 70% of adults return to the same nest areas annually (Caffrey, 1994; Massey and Fancher, 1989).

Two main nest areas for the terns on this coastline are located on beaches near the mouths of two freshwater drainages, Aliso/French Creeks and Santa Margarita Estuary. The Aliso/French Creek area, termed White Beach, is composed of a ≈20- to 40-m by ≈4-km stretch of sand that is partially enclosed with a 7.5×15.2 cm lattice-type fence (183 cm high), having a base of wire mesh. The fence deters human encroachment and obstructs chick dispersal. The Santa Margarita Estuary area consists of two main nesting locations: North Beach and Salt Flats. North Beach measures ≈60–90 m by ≈0.75 km and consists of sandy beachfront dunes with some grasses. It is also partially fenced to prevent human encroachment and chick dispersal. Salt Flats consists of ≈75 ha, unfenced area of scattered marsh vegetation; main nest areas are limited to a ≈150×120 m area adjacent to the River and a ≈60×10 m "island" created from dredged sediments slightly inland of the beach and south of the estuary.

Arrival and departure dates of adult terns at Camp Pendleton vary little among years. For the 1995–2001 interval comprising the current analysis, arrival dates occurred between April 18 and 20 and departure dates were from August 22 to September 9.

2.2. General procedures and data sets

Table 1 provides a description of the dependent and independent variables in the system.

2.2.1. Biological data

The two forms of biological information were reproduction-monitoring data and predator-removal data. Reproduction-monitoring data were obtained from detailed reports of reimbursable funds agreements between the U.S. Department of the Navy, Southwest Division, Naval Facilities Engineering Command (NAVFAENGCOM), San Diego, CA and The Zoological Society of San Diego, San Diego, CA (see Foster, 1996, 1997, 1998, 1999, 2000, 2001, 2002). Predator-removal data were obtained from reports of reimbursable funds agreements between NAVFAENGCOM, the U.S. Department of Agriculture, Wildlife Services (USDA/WS), El Cajon, CA, and the USDA/WS Management Information System.

Reproduction monitoring involved the identification of new nests, eggs, and fledglings. Nesting areas were lined off in 15×15 or 30×30 m numbered grids. This allowed for determinations of nest construction, distribution, egg-laying chronology, clutch size, incubation, as well as adult, chick, and fledgling counts—records of reproductive success and mortality. Observers carefully walked back and forth among grids recording measurements on each search date. They also noted predator sign or activity to assist with

Table 1
Description of dependent and independent variables

Variable	Variable name	Description
Y or X_B	adults	the number of adult terns observed
	totnests	the number of total tern nests observed
	eggs	the number of tern eggs observed
	fledglings	the number of tern fledglings observed
X_B	actnests	the number of active tern nests
	adincub	the number of adults incubating eggs
	badout	1 if there was a bad event, and 0 otherwise
	totalpred	the number of predators removed
X_E	predremhrs	the number of hours spent on site by predator-removal staff
	monitoringhrs	the number of hours spent on site by monitoring staff
	totalhrs	predator-removal hours plus monitoring hours
X_M	precip	the amount of precipitation in centimeters
	avgtemp	the average daily temperature in Celsius
	avgwspd	the average daily wind speed in kilometers per hour
	dewpt	the dew point in degrees Celsius

predator-removal efforts. Typically, observers made intensive searches of colony areas multiple times per week, with numbers of searches dependent upon funding.

Four variables were analyzed as dependent variables (i.e., total nests, total eggs, total fledglings, and total adult terns). During incubation, male and female terns tenaciously stay on the nests (eggs). Thus, numbers of active nests (Actnests) and numbers of adult terns incubating nests (Adincub) were chosen as key measures of nesting activity. To reflect deleterious events upon reproduction, we generated a dichotomous variable of nest, egg, fledgling, or adult bird destruction (Bad Outcome); this served as a gross predictor of weather, predator, or other induced loss.

Predator removal to improve reproductive success of the terns was a continuous, 7-day/week activity. Predator removal began about 1 month before arrival of the terns and continued until their departure (i.e., essentially March–August inclusive). Predator removal sought to create a "predator-free" zone around the combined nesting areas. Although the exact size of this "zone" varied both within and between years depending upon animal behavior, predator removal was intensely practiced at all nesting areas and within ≈ 1–4 km approaches (i.e., drainages) leading to these areas.

The techniques used for predator removal included: avicides (i.e., 3-chloro-*p*-toluidine hydrochloride), bal-chatri traps, cage traps, conibear traps, pole traps, padded-jaw leg-hold traps, snares, spotlighting, and shooting (see Butchko, 1990; Butchko and Small, 1992; Hyngstrom et al., 1994). Terrestrial mammalian predators were euthanized at the time of capture, but raptor species were translocated out of the area, and if injured, these birds were treated by a local raptor rehabilitation center.

Diverse species of avian and mammalian predators/scavengers were removed, with total predator numbers (Totalpred) used as an independent variable. An example of predator-removal data is shown in Table 2. In 1999, a total of 312 predators/scavengers, representing 11 mammalian and 14 avian species, was removed. This reflected 3105 cage trap-nights, 1438 padded-jaw leg-hold trap-nights, and 589 raptor trap-nights (English, 1999).

Table 2
Representative summary of predator removals–1999

Species	Scientific name	Number
American crow	*Corvus brachyrhynchos*	41
American kestrel	*Falco sparverius*	5
Barn owl[a]	*Tyto alba*	36
Black-crowned night heron	*Nycticorax nycticorax*	1
Bobcat	*Felis rufus*	12
California ground squirrel	*Spermophilus beecheyi*	64
Common raven	*Corvus corax*	30
Cooper's hawk	*Accipiter cooperi*	1
Coyote	*Canis latrans*	20
Feral cat	*Felis catus*	5
Feral dog[b]	*Canis familiaris*	1
Gopher snake[b]	*Pituophis catenifer annectens*	1
Great blue heron	*Ardea herodias*	3
Great horned owl[a]	*Bubo virginianus*	8
Long-eared owl[a]	*Asio otus*	1
Long-tailed weasel	*Mustela frenata*	2
Meadow lark	*Sturnella neglecta*	1
Northern harrier hawk	*Circus cyaneus*	1
Peregrin falcon	*Falco perigrenus*	1
Raccoon	*Procyon lotor*	5
Red-tailed hawk	*Buteo jamaicansis*	1
Southern Pacific rattlesnake	*Crotalus viridis oregamus*	1
Striped skunk	*Mephitis mephitis*	4
Western gull	*Larus occidentalis*	5
Virginia opossum	*Didelphis virginiana*	31

[a] All or some of these species taken to a wildlife rehabilitation center.

[b] All of these species were released on site or relocated to another part of Camp Pendleton.

2.2.2. Economic data

Annual fiscal budgets for both reproduction-monitoring and predator-removal agreements were provided by NAVFAENGCOM. Budget structures for the agreements differed. A typical breakdown for the reproduction-monitoring contracts was: Monitoring labor (≈ 55%), report preparation (≈ 10%), project coordination (≈ 9%), site preparation (≈ 3%), data entry (≈ 3%), material and supplies (≈ 2%), avian-predator rehabilitation (≈ 1%), overhead (≈ 17%), with no equipment costs (0%). Typical predator-management budgets allocated money for: Labor (≈ 68%), vehicle operation (≈ 12%), materials and supplies (≈ 2%), equipment (≈ 1%), training (≈ 1%), and overhead (≈ 16%).

Table 3 provides 2003 values (current) for the reproduction-monitoring and predator-management budgets during the study. Budgets were essentially stable, with only modest inflation-related increases. Summing the two budgets showed that 1998 and 1999 were the highest and lowest funded years, respectively. The highest budget year for reproduction monitoring was 1998 and the lowest was 1996. The highest predator-management budget occurred in 1996 and the lowest occurred in 1999. The high 1996 budget for predator removal can be explained partially by overtime pay policy; compensation time was provided in lieu of overtime during subsequent years to constrain costs.

Economic influences on the dependent variables were treated as proxy variables. Budget data were converted to personnel time (US$/h) spent monitoring reproduction or controlling predators. We created proxy variables because precise daily expenditures for labor costs were not recorded. However, the time and date that staff spent at the site were recorded precisely and could be converted to an hourly fee. Reproduction monitoring (Monitorhrs), predator management (Predhrs), and the composite of these (Totalhrs) were developed to reflect budgetary impacts on the dependent variables.

2.2.3. Meteorological data

Including meteorological variables in the system allowed for the identification of possible environmental stressors that were not addressed elsewhere in the analysis. Extreme precipitation was expected to correlate with flooding or standing water on beaches, potentially destructive or toxic events for nests or foraging shorebirds.

Table 3
Predator-removal and reproduction-monitoring budgets

Year	2003 Dollars[a]					
	Predator budget (US$)	Rank	Monitor budget (US$)	Rank	Total budget (US$)	Rank
1995	76,170	2	71,046	6	147,216	5
1996	78,753	1	68,477	7	147,230	4
1997	73,019	4	76,594	3	149,613	3
1998	73,165	3	81,275	1	154,440	1
1999	70,366	7	75,890	4	146,256	7
2000	71,601	6	75,328	5	146,929	6
2001	72,763	5	80,005	2	152,768	2

[a] Adjusted for inflation.

Specific weather data for dates encompassing tern activity at the site were obtained from National Atmospheric and Oceanic Administration [NOAA] (1996–2001). Four independent variables were used to assess potential weather influences upon the reproduction variables: average daily precipitation (Precip; cm), average daily air temperature (Avgairtemp; °C), average daily wind speed (Avgwspd; km/h), and average daily dewpoint (Dewpt; °C). Average values were used to reflect the average climatic conditions of the day. High and low temperatures were initially used in the analysis but decreased the explanatory power of the analysis, and were omitted in favor of average values and an alternate measure of meteorological extremes. To capture the effects of climatic extremes, the variable Bad Outcome was added for this purpose. This variable represented potential meteorological events that could significantly impact the terns.

2.3. System

Reproduction of California least terns at Camp Pendleton was viewed as a system of biological, economic, meteorological, and other unmeasured variables, with combinations of these variables influencing the number of terns observed (Fig. 2). That is, interactions among biological (X_B), economic (X_E), meteorological (X_M), and other (X_O) variables determine each of the four dependent reproduction variables (i.e., Y_{nests}, Y_{eggs}, $Y_{fledglings}$, and Y_{adults}). Observations for those dependent variables not used in a given regression equation were still included as independent variables for purposes of prediction. For example, if the number of adult terns observed was the dependent variable of concern, then nests, eggs, and fledglings became predictor variables for that analysis.

Arrows (Fig. 2) indicate the direction of the postulated impacts, with the dashed arrow indicating the effect of diverse "other" variables that were unavailable as data. While the overall influence of factors, such as fisheries resources, toxicological impacts, and catastrophic events (e.g., surge tide, red tide), were undoubtedly important to the observed number of terns, these effects could not be estimated for the current model. Our empirical analysis attempts to estimate the relative magnitudes of X_M, X_E and X_{B-Y} on

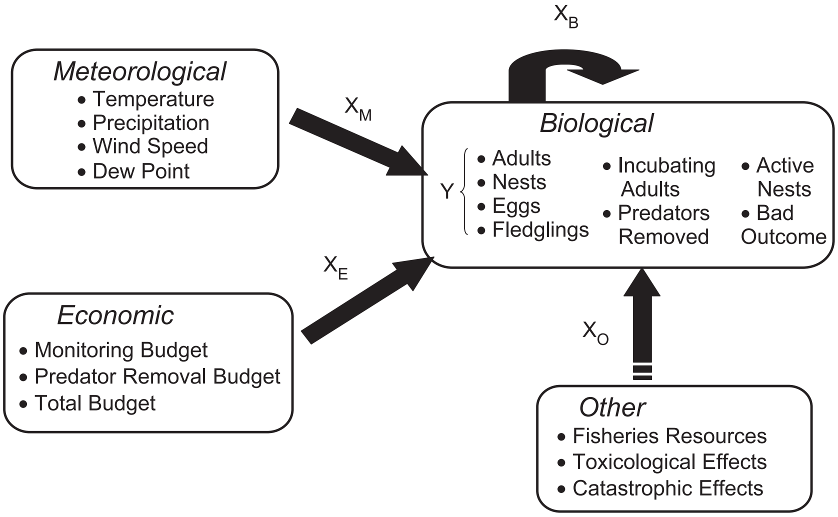

Fig. 2. Schematic of the Tern Reproduction System and interaction of biological, economic, meteorological, and other variables.

Y. That is, we are attempting to estimate the relative size of each of the arrows on *Y* (Fig. 2).

The bio-econometric model representing the system can be written as:

$$Y = \beta_1 + \beta_2 X_{\mathrm{B-Y}} + \beta_3 X_{\mathrm{M}} + \beta_4 X_{\mathrm{E}} + u_t \tag{1}$$

where $X_{\mathrm{B-Y}}$ represents the biological variables in the system less the biological variable that is the dependent variable.

2.4. Model and data analysis

There were 354 observations in our sample. The observations reflect occurrence of reproduction monitoring activities during the seven successive years of April–August nesting seasons. Years were condensed to represent observations made during the breeding season, omitting days without a recorded observation. Therefore, each "year" consisted of approximately 50.5 days. A correlation analysis was used to examine the positive/negative agreement and magnitude of relationships between pairs of variables and assess theoretical concurrence of predicted relationships. The results of the correlation were then matched with the model selection criteria to determine the final number variables in the system.

Multiple regression analyses were computed using the cited independent variables and four dependent variables in the system. All variables were tested for stationarity, using the Augmented Dickey Fuller (ADF) and Phillips–Peron (PP) tests (Enders, 1995). All of the dependent variables were stationary at the level and the independent variables that were nonstationary were made difference stationary. In all of the regressions, the Akaike–Schwartz criterion was used as the model selection criteria (Enders, 1995).

3. Results

3.1. Regression analysis

Table 4 provides descriptive statistics for each of the 15 variables in the system. The results of the four separate regressions are given in Table 5. Shaded boxes indicate that the variable was lagged. One period in this model was ≈2 days. Variables were lagged to reflect that their influence on contemporaneous dependent variables was exerted in earlier periods. Sample sizes were noticeably different than the number of observations as a result of missing data in some series and the inclusion of lagged variables. Lagged variables were determined by the results of the Akaike–Schwartz criteria.

3.1.1. Biological variables (X_B)

The biological variables provided a number of consistent predictive relationships in each of the four

Table 4
Descriptive statistics for the variables per monitoring day

Variables	Mean	S.D.
Adults	145.22	213.66
Totnests	318.98	363.17
Eggs	18.58	79.41
Fledglings	26.30	77.32
Actnests	73.91	150.74
Adincub	0.13	1.05
Totalpred	1.46	2.28
Bad outcome	0.22	0.42
Predremhrs	6.96	3.36
Monitorhrs	3.12	4.80
Totalhrs	12.00	27.60
Precip	0.03	0.17
Avgairtemp	18.05	14.58
Avgwspd	5.34	2.16
Dewpt	−10.83	15.88

equations. Although some disparities in the sign and lack of significance for certain coefficients occurred, the main reproduction variables of Adults, Totnests, Eggs, and Fledglings generally were related and predictive of observed counts for the other dependent variables when used as regressors. Moreover, counts of active nests (Actnests) and adult birds sitting on nests (Adincub) proved predictive of Eggs and Fledglings (i.e., negative sign showed that incubation decreased as chicks began to fly). Together, the pattern of coefficients generally attests to the strong relationships of these variables, and the strong interdependencies among diverse factors reflective of reproduction in the terns.

Highlights of key biological effects evident in the regression analyses showed that number of adult terns (Adults) was an important, positive predictor in the Y_{nests} equation and the Y_{eggs} equation. Not surprisingly, this demonstrated that Adults were important to observations of Totnests and Eggs. Adults yielded no prediction (though a positive coefficient) in the $Y_{\text{fledglings}}$ equation. It must be noted that a hierarchy of counting accuracy is undoubtedly present in observational counts of the four dependent variables, with Totnests, Actnests, and Eggs the most definitive counts, and with Fledglings and Adults posing greater measurement

Table 5
Coefficients of separate regression analyses using four dependent variables Y_{nests}, Y_{eggs}, $Y_{\text{fledglings}}$, and Y_{adults} (standard error); shaded areas represent lagged variables

Independent variables	Dependent variables/development stage			
	Adults	Total nests	Eggs	Fledglings
Constant	4.92 (35.44)	-195.056 (78.91)	35.47 (27.7)	-14.13 (8.70)
Actnests	0.144** (.065)	-	1.43* (.05)	-0.151* (.02)
Adincub	3.14 (5.56)	-5.20 (12.47)	38.64* (4.98)	4.24* (1.63)
Adults	-	.267** (.131)	.09** (.05)	0.013 (.015)
Totnests	.203* (.03)	-	-.107 (.02)	.075* (.007)
Eggs	-.086** (.036)	.73* (.055)	-	0.004 (.008)
Fledglings	.359** (.208)	4.34* (.49)	0.022 (.167)	-
Totalpred	0.47 (1.11)	-.33 (2.58)	-.33 (.89)	0.14 (.28)
Bad outcome	-5.79 (10.68)	-31.43 (24.68)	-11.05 (8.63)	-3.71 (2.69)
Predremhrs	9.59 (19.51)	39.37 (45.21)	4.479 (16.22)	-13.18** (5.19)
Monitorhrs	35.2 (40.47)	35.84 (79.47)	35.98 (27.64)	26.43** (12.16)
Totaltime	8.97*** (5.02)	9.2 (11.80)	0.128 (4.31)	4.43* (1.34)
Precip	-8.75 (23.78)	14.16 (54.43)	-7.25 (19.022)	1.3 (6.08)
Avgairtemp	-0.79 (.84)	2.95 (1.90)	-0.44 (.65)	0.12 (.21)
Avgwspd	1.2 (1.76)	2.63 (4.07)	-1.70 (1.41)	-0.49 (.45)
Dewpt	0.789 (.64)	0.111 (1.46)	-.116 (.51)	0.23 (.16)
Sample size	236	235	235	236
AIC	10.05	11.69	9.60	7.31
SBC	10.27	11.9	9.81	7.52
R^2	0.52	0.66	0.93	0.54

* Significant at the 1% level.
** Significant at the 5% level.
*** Significant at the 10% level.

difficulties due to flight. Totnests was important in the Y_{adults} and $Y_{\mathrm{fledglings}}$ equations. All coefficients were positively related to these dependent variables. This positive relationship between Totnests and adults reflects the fact that an increase in the total number of nests observed is in part a reflection of an increase in the number of adults creating those nests. The positive nature of the relationship between Totnests and fledglings indicates that more nests will most likely lead to a greater yield of fledglings.

3.1.2. Economic variables (X_E)

Results for the economic variables indicated that Monitorhrs was a key, positive predictor for $Y_{\mathrm{fledglings}}$, and that Predremhrs also accounted for sizable variance in predicting $Y_{\mathrm{fledglings}}$ (negative coefficient). In short, the greater monitoring dollars invested in hours used to measure tern reproduction, the more Fledglings counted. Totalhrs yielded a strong positive relationship with $Y_{\mathrm{fledglings}}$ and Y_{adults}. We contend that these proxy variables reflecting labor costs indicate that both reproduction monitoring and predator removal time are crucial to the observance of greater numbers of Fledglings and Adults.

Predremhrs was important and negative in the $Y_{\mathrm{fledglings}}$ equation. Although coefficients were negative for fledglings, this is probably due to the difficulty in protecting new-flying terns from predators (especially avian predators). When predation of fledglings occurred, personnel could expend significant amounts of time trying to remove predators to protect this dwindling age class. Counts of terns at this stage of development are tenuous and may have produced simply no consistent pattern of relationship between fledgling counts and staff hours spent in predator removal activities.

3.1.3. Meteorological (X_M)

The meteorological variables were of minimal importance in accounting for observational counts at any developmental stage (Adults, Nests, Eggs, or Fledglings). This result is surprising in that meteorological effects are generally thought to play an important role in the terns' reproductive success. Descriptive statistics (Table 4) for these variables also suggested that weather conditions were generally mild and stable across years and seasons. However, the mean values of variables often obscure the importance of brief, within-day wind gusts, tidal events, and other negative weather events.

3.2. Forecast analysis

The regression analysis identified and measured the effects of the independent variables (X_{B}, X_{M}, and X_{E}) on the dependent variables (Y_{adults}, Y_{totnests}, Y_{eggs}, and $Y_{\mathrm{fledglings}}$) and this relationship can be used to project future values of the dependent variables. The regression analysis was used to obtain the estimates of the coefficients, and from this we were able to formulate equations to forecast the number of adults, nests, eggs, and fledglings, given fixed increases of 25%, 50%, and 100%, in the X_{E} variables.

We performed analysis of four separate equations for each of our dependent variables. In each equation, we used the mean values of the biological and meteorological variables and scaled up each of the economic variables independently. Initially, it was expected that increasing the total hours would cause the greatest benefit to production for each development stage since total hours is simply monitoring hours plus predator-removal hours. However, the results of the forecast analysis clearly showed that the relationship between dependent variables and the economic variables is a dynamic process that changes with development stages.

Total nests and fledglings were influenced most by monitoring hours. Even 25% increased funds for this activity was forecasted to yield 105.6% and 38.6% more nests and fledglings counts, respectively (Table 6). New nests lack prey items so it is not necessary for predator removal staff to invest more time in protecting these nests until the presence of eggs. However, monitors invest many hours in the discovery and recording of new nests. The importance of monitoring hours in forecasting total nests confirms that monitoring pays big dividends for finding nests and counting elusive young birds.

Predator removal hours were forecasted to yield the greatest return for producing future numbers of eggs. In this case, a 25% increase in funding for predator-removal hours produces 10.4% more eggs. This effect could be due to the long-lasting impact or initial removal of resident predators, because time is required for the ingress of predators which coincides

Table 6
Percent increase forecast for the dependent variables as a result of an increase in the independent variables

Development stage/ dependent variable	Scaled independent variable								
	Monitor hours (%)			Predator-removal hours (%)			Total hours (%)		
	25	50	100	25	50	100	25	50	100
Adults	7.6	14.1	24.7	4.8	9.1	16.7	8.1	16.1	32.2
Total nests	105.6	211.5	423.2	29.1	58.4	117.1	1.2	2.6	5.5
Eggs	4.2	8.5	16.9	10.4	20.8	41.5	4.2	8.4	16.7
Fledglings	38.6	77.2	154.3	−42.9	−85.8	−171.7	24.9	49.8	99.5

with nesting and egg laying. Prior to the arrival of the terns, predator removal is important to prepare the site and provide some predator removal for protection of the adults upon arrival. However, as the site evolves and nests are formed, there is less of a role for predator-removal staff until prey items (i.e., eggs) are available in the nests. When eggs are available for predators in the nests, the efforts of predator-removal staff again become crucial to the protection of eggs.

The difficulty in protecting fledglings is reflected by the negative sign on the coefficient for predator-removal hours in the fledgling forecast. Fledglings are mobile, erratic, and vulnerable to a multitude of predators; this makes protection complex and time consuming. In many cases, predator-removal staff increases their daily work hours, but remove fewer predators. This explains the negative relationship between forecasts of greater funds for predator removal hours and the fledgling's variable.

Finally, total hours was the most influential in forecasting the future number of adults, but less influential in the other three equations. Specifically, a 25% increase in the funding of both monitoring and predator-removal hours yields an 8.1% increase in the production of adults. Theoretically, this makes sense. Both monitoring and predator-removal staff invest an intensive amount of time prior to the arrival of adults. During this time, staff prepares the site through habitat management, mark the nest areas, erect protective barriers, and remove resident predators.

4. Discussion

This study sought to determine whether reproduction-monitoring and predator-management budgets affect the observed number of tern adults, nests, eggs, and fledglings. If we accept the premise that proxy hours for these budgets are valid indices of fiscal effects, the current results support this contention. In all cases, except for predator-removal time as a regressor of numbers of nests and fledglings, the proxy variables were associated with greater counts of the dependent variables. This is indirect evidence of increased production based on increased budgets. At the very least, these economic variables appear to be as potent as selected biological variables and more potent than selected meteorological variables in accounting for variance in diverse measurements of California least tern reproduction.

Although numerous studies have attempted to provide benefit-cost analyses of TS/ES expenditures, most have involved largely theoretical treatises of citizens' "willingness-to-pay" for intrinsic, nonconsumptive uses of wildlife (e.g., Boyle and Bishop, 1987; Loomis and Ekstrand, 1997; Whitehead, 1992) or alternate measures of cost-utility analysis (Cullen et al., 2001). The current study differs from much prior research because it provides an empirical analysis of actual fiscal data involved in the protection of a recognized ES. A 1997 report by the Majority Staff of the U.S. House of Representatives estimated total spending by all federal agencies related to TS/ES for that year at US$501,625,000 (Office of the Chief Counsel, 1998). Our data reveal that >US$1.04 million (net current value) was spent to recruit California least terns at Camp Pendleton during 1995–2001; while estimates of adult terns during this period increased from 363 to 993 adult pairs—a rough tripling of nesting pairs for the investment (Foster, 1996, 2002).

The forecasted results are consistent with the role of the economic variables at each reproductive stage. In particular, to increase the number of adults observed, it is most effective to increase the total time spent at the site (monitor hours plus predator-removal hours), which reflects that monitoring and predator-removal staff are heavily involved in the preparation of the site prior to the arrival of adults. Increasing the number of monitoring hours is the most efficient way to increase the future number of total nests observed, or in other words, the more time that monitors spend in the field, the greater the number of nests detected. Later in the season, as eggs are more prevalent at the site, the work of predator-removal staff becomes increasingly important to protect the eggs, which indicates that the effectual way to increase the number of eggs is to increase the number of predator-removal hours. As the eggs become fledglings, and have some limited defense against predators, the role of monitors was again the most crucial factor among the economic variables in determining future values of fledglings.

The lack of importance of the meteorological variables in predicting the dependent variables warrants comment. We believe that the use of dummy variables or improved ways of deriving variables that reflect short-term, disastrous environmental consequences is important. Annually, some nests, eggs, and chicks are lost to high tides, rainfall-induced flooding of localized nest areas, etc. (Foster, 2002). Our use of daily meteorological variables probably attenuated these effects. Future analyses of TS/ES recruitment need to include improved quantifiable indices of potential catastrophic meteorological incidents upon dependent variables.

In conclusion, our results are part of a growing body of literature that attests to the benefits of active predator management as a means of enhancing recruitment of TS/ES (Butchko, 1990; Butchko and Small, 1992; Engeman et al., 2002). Except for the potential of fencing to deter some human and predator encroachment at nest sites in this study, the active removal of predators was associated with the resultant prediction of increased adults and eggs; this convinces us that predator management is crucial to recruitment. Although reproduction monitoring appeared to be more influential in predicting adults, eggs, and fledglings, monitoring is a passive, surveillance-type activity. Predator management was the main active, wildlife-intervention activity involved in this study. As we discussed, monitoring also helps to focus predator-management activities.

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